Art. IX.—*Observations with Aneroid and Mercurial Barometers and Boiling Point Thermometers.*

By Thomas Walker Fowler, M.C.E., F.R.G.S.

[Read 10th October, 1895.]

In connection with engineering and general survey work, as well as in geographical investigations, it is frequently convenient to determine, approximately, the attitudes of different points from observations of barometric pressure at such points. Various instruments are used for this purpose, the most convenient and portable being, undoubtedly, the aneroid barometer, and the most trustworthy, the mercurial barometer of either the Fortin, or syphon type provided that the tube be of large bore. The latter requirement causes the instrument to be very heavy and neither portable nor convenient. Boiling-point thermometers form a third-class of instruments much less convenient than aneroid barometers, but decidedly more portable than mercurial ones even of small bore, as all mercurial barometers are very liable to damage from destruction of the vacuum through careless handling as well as from fracture of the tube. Delicate and fragile thermometers, undoubtedly, require careful handling, but much less so than mercurial barometers.

From 20th August last up to the present time, the writer made a series of observations for the purpose of determining the relative accuracy of instruments of the classes mentioned. They were made at his residence in Upper Hawthorn, Melbourne, the approximate altitude above sea level being 200 feet, and during the observations the atmospheric pressure varied considerably, the maximum recorded being 30·048 inches, and the minimum 29·020 inches.

For use as a Standard the Acting Government Astronomer (Mr. Baracchi), kindly placed at the writer's disposal a pedestal mercurial barometer of the Fortin type, made by Newman & Son, and numbered 122. The diameter of the tube is marked 0·380 inch. The adjustment of the fiducial point is made by raising

or lowering it, and the graduated scale by means of an adjusting screw instead of by altering the level of the mercury in the cistern as in the instruments of a more recent type. The attached thermometer is placed opposite the graduated scale at the upper end of the tube which is the only portion exposed. The distance from the thermometer bulb to the tube is $\frac{3}{16}$ inch. The instrument is one of those used in connection with Professor Neumayer's Meteorological Investigations in Victoria, and reads by vernier to 0·002 inch, and by estimation to 0·001 inch. The vacuum appears to be good. There is little doubt that the attached thermometer is more rapidly affected by variations of temperature than the mercury in the tube, and hence that the correction for temperature applied may at times have been incorrect to the extent of, say, 0·005 inch as a maximum (equivalent to a temperature error of 2 deg.). Probably the maximum reading error did not exceed 0·004 inch, and the writer is of opinion that differences of pressure as indicated by this barometer might be relied on to about 0·006 inch. The writer had not the opportunity of investigating for himself the correction for index error, nor did it seem necessary, as it would equally affect the whole of the observations and leave the differences unaltered.

No correction was applied for capillary depression, but the height of meniscus was measured several times and found to vary from 0·051 inch to 0·040 inch, corresponding to variations in the capillary depression of 0·002 inch, according to Guyot's Tables, page 340.

The instruments compared with the Standard barometer were as follows:—

1st. A Watkin 4½ inches Patent Aneroid, marked "Jewelled and Compensated, No. 161, Kilpatrick & Co., London and Melbourne." This instrument is graduated to 0·01 inch and can easily be read to 0·002 inch. It was made by Hicks, of London, and is the property of the Melbourne University.

2nd. A 2½ inches Aneroid, marked "Jewelled and Compensated, Kilpatrick & Co., London and Melbourne," and graduated to 0·05 inch and easily read to 0·01 inch. This aneroid was made by Short & Mason.

3rd. A $1\frac{3}{4}$ inch Aneroid, marked "Compensated, Kilpatrick & Co., London," graduated to 0·05 inch and easily read to 0·01 inch. This Aneroid was made by Barker & Co., of London.

The Aneroids, 1, 2 and 3, were altered by having a disk fixed to the end of the index and perpendicular to the plane of the dial for the purpose of eliminating parallax as suggested by Admiral Wharton in his "Hydrographical Surveying."

4th. A Mountain Mercurial barometer of the Gay Lussac syphon type, with verniers reading to 0·001 inch. The frame is marked Troughton & Simms, London, and the tube was made and filled by Yeates of Melbourne in December, 1894. The external diameter of the tube is 0·25 inch, and probable internal diameter 0·15 inch. A similar tube was in the frame when obtained by the writer, though, probably, that originally issued with it was larger. Its external diameter cannot however have exceeded 0·50 inch in any part, and portions of it must have been much less. The attached thermometer is fixed to the middle of the frame, and the outer portion of the bulb is exposed.

5th. A Boiling-point thermometer, marked 1,013,848, Kilpatrick & Co., Hicks' patent fixed zero K, C, 95, and graduated on stem from 193° to 213°·5 Fahr., the divisions being to 0°·05, and the length of the graduations $18\frac{5}{8}$ inch. The bore of the tube is fairly fine, and the external dimensions of the bulb are: length 2·25 inches, diameter 0·3 inch. The total length of the thermometer (which was made by Hicks) is 23·5 inches. It was placed in a steam jacketed tube attached to a copper boiler, and the distance from the bottom of the bulb to the water-level was never less than 5 inches. When the observations were in progress a glass tube manometer, filled with water, was attached to the apparatus at the level of the bulb, but the pressure indicated never exceeded 0·003 inch of mercury. During each boiling-point observation about two cubic inches of water were evaporated, and care was taken to have a considerable quantity of water left in the boiler.

The Observatory tests of the aneroids and boiling-point thermometer are given in Appendix A.

The results of every observation taken are given in the Appendix B. It will be noticed that the Watkin aneroid

behaves in a most eccentric manner, and that its variations are but very slightly indicated by the air pump test made at the Observatory on 20th December, 1894. The $1\frac{3}{4}$ inch aneroid worked very much better, but did not behave as it did under the air pump, whilst the $2\frac{1}{2}$ inch aneroid shows very well with the exception of one discordant observation, and its behaviour is very similar to what it was under the air pump.

Taking the whole of the results they fully justify (so far as they go) Mr. Edward Whymper's conclusion, "that the test which is usually applied of comparing for brief periods (minutes or hours) aneroids with mercurial barometers under the air pump is of little or no value in determining the errors which will appear in aneroids used at low pressure for long periods (weeks or months)."—"How to use the Aneroid," page 9.

The behaviour of the small bore Mountain mercurial is at first sight very peculiar, but is, undoubtedly, due to varying capillary action in the small instrument. No measurements of the heights of the meniscus were taken, but it was apparent that these were continually varying both in upper and lower limbs though principally in the latter where the meniscus at times entirely disappeared, and at other times exceeded considerably that in the upper limb. In every case the instrument was well tapped prior to taking a reading. It would appear that the readings of this barometer could be depended on to about 0·03 inch, and the error would be independent of altitude.

The boiling-point experiments resolve themselves into two sections, one taken with a glass spirit lamp, which was not sufficiently powerful to maintain a good supply of steam, and the other with a brass lamp which generated steam with ease. As might be expected the boiling points given by the former are all lower than those given by the latter. One of the observations (that on the 26th August, 4 p.m.) should undoubtedly be rejected, as the apparatus was at the time undergoing alterations and consequently the bulb was exposed to a mixture of air and steam instead of pure steam. Taking the second set of observations (sixty-seven in number), the maximum difference in the correction to standard is 0·048 inch as against 0·068 inch with the Mountain mercurial.

It may be mentioned that of eighty-one observations in all, thirty were taken with Yan Yean water, and the rest with rain water, but no perceptable difference in pressure was indicated from the alteration.

So far as they go the observations tend to show that pressures determined from boiling points are fairly trustworthy. It remains to be seen, however, how much the index error of the thermometer will vary with time, and this can only be done by repeating the experiments after the lapse of some years. Further the writer has not had the opportunity of applying the method at [illegible] altitudes, though determinations of the height of

After the word "giving" on line 13, page 173, insert, "1016 feet,".

[illegible] levelling. The first three [illegible] mometers much less sensitive than that described above. The aneroid barometers gave the following heights for the same mountain. Watkin (two observations) 1057 feet and 1082 feet. The $2\frac{1}{2}$ inch (two observations) 961 feet and 1042 feet; and the $1\frac{3}{4}$ inch (one observation) 927 feet.

Boiling-point thermometers are condemned emphatically by Mr. Whymper as the result of his experiments on the Andes, but the apparatus used by him seems to be much less sensitive than that used by the writer. Boiling-point thermometers are generally graduated from about 180 degs. to 212 degs., and are about 12 inches long, the bulbs are placed close to the water of which the supply is very limited, and the heating arrangements appear to be of a meagre character. In some experiments made by the writer with a Greiner Boiling-Point apparatus, constructed about 1860, and filled with water so as to just touch the bottom of the bulb, the water had all boiled away before the "pumping" action of the thermometer had ceased. Mr. Whymper's experiments were made with Henderson's apparatus, in which the heating agent is a composition candle. The writer has not used this apparatus, but questions its ability to give a full supply of steam at a high altitude.

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The boiling-point experiments resolve themselves into two sections, one taken with a glass spirit lamp, which was not sufficiently powerful to maintain a good supply of steam, and the other with a brass lamp which generated steam with ease. As might be expected the boiling points given by the former are all lower than those given by the latter. One of the observations (that on the 26th August, 4 p.m.) should undoubtedly be rejected, as the apparatus was at the time undergoing alterations and consequently the bulb was exposed to a mixture of air and steam instead of pure steam. Taking the second set of observations (sixty-seven in number), the maximum difference in the correction to standard is 0·048 inch as against 0·068 inch with the Mountain mercurial.

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So far as they go the observations tend to show that pressures determined from boiling points are fairly trustworthy. It remains to be seen, however, how much the index error of the thermometer will vary with time, and this can only be done by repeating the experiments after the lapse of some years. Further the writer has not had the opportunity of applying the method at considerable altitudes, though determinations of the height of Arthur's Seat made by him with boiling thermometers were fairly satisfactory, four determinations giving 1016 feet, 981 feet and 986 feet respectively, as against 996 feet determined by spirit levelling. The first three observations were taken with thermometers much less sensitive than that described above. The aneroid barometers gave the following heights for the same mountain. Watkin (two observations) 1057 feet and 1082 feet. The $2\frac{1}{2}$ inch (two observations) 961 feet and 1042 feet; and the $1\frac{3}{4}$ inch (one observation) 927 feet.

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Appendix A.

Corrections to reading of Boiling-point thermometer as per Kew Certificate. Corrections to nearest 0°·05.

From 194° to 205° (tested at 8 points on scale)	+0°·15
At 212° - - - - -	+0°·10

Corrections to Aneroids as per tests at Melbourne Observatory.

Pressure.	Watkin.	$2\frac{1}{2}$ inch.	$1\frac{3}{4}$ inch.
30·5	+0·07	+0·07	...
30·0	+0·10	0·00	+0·17
29·0	+0·10	−0·08	+0·05
28·0	+0·05	−0·15	−0·02
27·0	−0·23	−0·27	−0·09
26·0	...	−0·31	−0·14
25·0	...	−0·33	−0·20
24·0	...	−0·33	...

APPENDIX B.

Results of Observations expressed as corrections to make Observed readings of instruments agree with that of Standard. Barometer pressure corresponding to boiling point by Guyot's Tables.

Date.		Time.	Standard Mercurial at 32 degrees.	Mountain Mercurial Correction.	Aneroid Corrections.			Boiling Point Thermometer Correction.
					Watkin.	2½ inch.	1¾ inch.	
			in.	in.	in.	in.	in.	in.
Aug.	20	8 a.m.	29·484	−0·058	...	...	−0·136	...
	21	8 a.m.	29·491	−0·043	...	...	−0·129	...
	22	8 a.m.	29·640	−0·051	...	...	−0·080	−0·044
		9 p.m.	29·473	−0·060	...	...	...	−0·053
	23	4·45 p.m.	29·427	−0·061			−0·123	−0·046
	24	9 a.m.	29·422	−0·060	−0·055	−0·068	−0·128	...
		9.50 a.m.	29·401	−0·064	...	...	...	−0·048
		1 p.m.	29·284	0·053	...	...	..	−0·035
		2.40 p.m.	29·207	−0·045	...	...	...	−0·037
		4 p.m.	29·169	−0·046	...	...	..	−0·040
		6 p.m.	29·129	−0·042	...	...	...	−0·045
	25	9.15 a.m.	29·139	−0·046	+0·027	−0·091	−0·121	...
		10 a.m.	29·149	−0·037	...	...	...	−0·048
		4.45 p.m.	29·174	−0·040	...	...	...	−0·053
	26	8.15 a.m.	29·274	−0·025	−0·022	−0·076	−0·116	−0·045
		4 p.m.	29·277	−0·028	...	...	...	+0·004
		6.30 p.m.	29·298	−0·016	...	...	...	−0·045
	27	8 a.m.	29·144	−0·051	+0·027	−0·089	−0·049	−0·044
		7.45 p.m.	29·134	−0·026	...	...	...	−0·069

APPENDIX B—*(Continued).*

Date.	Time.	Standard Mercurial at 32 degrees.	Mountain Mercurial Correction.	Aneroid Corrections.			Boiling Point Thermometer Correction.
				Watkin.	2½ inch.	1¾ inch.	
		"	"	"	"	"	"
Aug. 28	8 a.m.	29·281	−0·038	−0·023	−0·079	−0·119	−0·097
	8.30 p.m.	29·535	−0·043		...	...	−0·049
29	8.30 a.m.	29·731	−0·040	−0·275	−0·029	−0·039	−0·060
	8 p.m.	29·742	−0·044	...	..	...	−0·061
30	9.15 a.m.	29·596	−0·064	−0·148	−0·134	−0·164	...
	9.45 a.m.	29·581	−0·065	...	..	...	−0·056
	8 p.m.	29·586	−0·021	−0·231	−0·044	−0·094	−0·053
31	8.30 a.m.	29·770	−0·045	−0·321	−0·030	−0·050	...
	8.45 a.m.	29·777	−0·045	...	...	...	−0·061
	6 p.m.	29·671	−0·067	...	...	...	−0·061
Sept. 1	9.15 a.m.	29·685	−0·053	−0·343	−0·035	−0·075	...
	9.45 a.m.	29·685	−0·051	...	...	...	−0·059
	3 p.m.	29·664	...	...	...	...	−0·035
	6.45 p.m.	29·674	.	.	...	...	−0·070
2	8.15 a.m.	29·513	−0·059	−0·079	−0·057	−0·087	...
	8.45 a.m.	29·498	...	...	...	...	−0·062
	1 p.m.	29·279	...	−0·028	...	..	−0·058
	8.15 p.m.	29·083	...	+0·017	...	..	−0·061
	11.15 p.m.	29·020	...	+0·031	...		−0·060
3	8 a.m.	29·204	−0·042	+0·011	−0·096	−0·146	...
	8.15 a.m.	29·209	...	...	...	...	−0·052
	8 p.m.	29·290	...	+0·013	...	...	−0·053
4	8 a.m.	29·262	−0·041	−0·022	−0·098	−0·138	...
	8.20 a.m.	29·269	...	...	...	...	−0·062
	5 p.m.	29·246	..	...	...	...	−0·061
	8 p.m.	29·240	...	...		...	−0·056
5	8 a.m.	29·354	−0·041	−0·026	−0·076	−0·126	...
	9.25 a.m.	29·397	...	..	...	...	−0·064

APPENDIX B—*(Continued).*

Date.	Time.	Standard Mercurial at 32 degrees.	Mountain Mercurial Correction.	Aneroid Corrections.			Boiling Point Thermometer Correction.
				Watkin.	2½ inch.	1¾ inch.	
		"	"	"	"	"	"
	8 p.m.	29·570	...	...	...	...	−0·067
Sept. 6	8.30 a.m.	29·628	−0·039	−0·099	−0·052	−0·092	...
	10 a.m.	29·535	...	...	...	...	−0·058
	8 p.m.	29·579	...	...	...	...	−0·070
7	8.30 a.m.	29·642	−0·049	−0·149	−0·038	−0·078	...
	9.15 a.m.	29·656	...	...	...	...	−0.064
	2.45 p.m.	29·609	...	...	...	...	−0·069
	7.30 p.m.	29·646	...	...	...	...	−0.074
8	9.30 a.m.	29·410	−0·049	−0·023	−0·070	−0·130	..
	10.30 a.m.	29·413	...	...	...	...	−0·066
	4 p.m.	29·396	...	...	...	...	−0·071
	9 p.m.	29·438	...	...	...	...	−0·070
9	8.30 a.m.	29·206	−0·044	+0·006	−0·104	−0·144	...
	10.15 a.m.	29·176	...	...	...	...	−0·068
	5.30 p.m.	29·208	...	...	...	...	−0·065
	9·30 p.m.	29·332	...	...	...	...	−0·070
10	8.15 a.m.	29·619	−0·048	−0·151	−0·051	−0·061	...
	8·45 a.m.	29·636	...	...	...	...	−0·066
	8 p.m.	29·741	.	...	...	...	−0·074
11	8 a.m.	29·848	−0·041	−0·385	−0·022	−0·062	...
	8.30 a.m.	29·857	...	...	...	...	−0·065
	9 p.m.	29·799	...	...	...	...	−0·075
12	8.30 a.m.	29·722	−0·059	−0·341	−0·048	−0·088	..
	10.15 a.m.	29·667	...	...	...	...	−0·065
	9.15 p.m.	29·876	...	...	..	...	−0·076
13	8.30 a.m.	29·955	−0·033	−0·439	−0·015	−0·045	...
	10 a.m.	29·944	...	...	...	...	−0·073
15	9.15 a.m.	29·438	−0·050	−0·035	−0·082	−0·112	...

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